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Performance of High-Resolution Numerical Weather Predictions with a Rapid Updating Cycle for Urban Runoff Forecasting

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Abstract: Rainfall forecasts based on numerical weather predictions are a fairly new tool within the urban drainage community. That is despite the fact that they provide longer forecast horizons than radar-based forecasts, which could be valuable for integrated management of urban drainage-wastewater systems. High-resolution numerical weather predictions with a high updating frequency are here used as forcing in a runoff model, which provides flow forecasts up to 10 hours ahead. Evaluation is done in terms of exceedance of a flow threshold. Results show trustworthy predictions on horizons less than two hours. For longer horizons, the True Positives Rate and the Positive Predictive Value decrease to around 0.2 and 0.3, respectively.

Keywords: Numerical Weather Prediction; Urban runoff forecasting; Threshold exceedance evaluation

1. INTRODUCTION

Radar-based precipitation forecasts are skilful up to 3 hours ahead, the length depending strongly on the weather conditions (Thorndahl et al., 2017). However, many problems in integrated management of urban drainage-wastewater systems exist on time scales beyond this short horizon. Numerical Weather Predictions (NWP) can increase forecast horizons but at the expense of reduced spatial and temporal resolution. NWP is a fairly new tool within urban hydrology and there is thus little research into their performance as forcing for urban drainage models.

In this contribution, we investigate the use of a newly developed operational NWP nowcasting system at the Danish Meteorological Institute (DMI). The system assimilates additional observations of specific relevance to precipitation, including radar observations and cloud data, to improve the initial conditions (Korsholm et al., 2015). The NWP product is used to force a conceptual rainfall-runoff model for predictions of flow at the outlet of a sewer catchment with a forecast horizon up to 10 hours. The evaluation of skill is done in terms of predictions of high/low flow domains (Vezzaro et al, 2017).

2. MATERIALS AND METHODS

2.1 Data and case study

The case study for this contribution is the Dæmningen combined sewer catchment, which is located in Copenhagen, Denmark. The catchment is approximately 30 km^2 and a flow gauge is located at its outlet, recording flow measurements at a two-minute resolution. Observed rainfall data are available from three rain gauges inside the catchment at one-minute resolution. Flow and rain gauge data are available for the calendar years of 2016 and 2017.

Figure 1 shows the sewer catchment boundary with the main sewer pipes, the location of the flow gauge, and the center of the NWP grid-boxes (i.e. where the NWP forecasts are available).

The NWP product is based on the HIRLAM model and it has a spatial resolution of approximately 3 km and a temporal resolution of 10 minutes. The forecast horizon is 10 hours and it has a rapid updating cycle as a new forecast is produced every hour. The NWP product comes with a half hour delay compared to the last observations assimilated into the model.

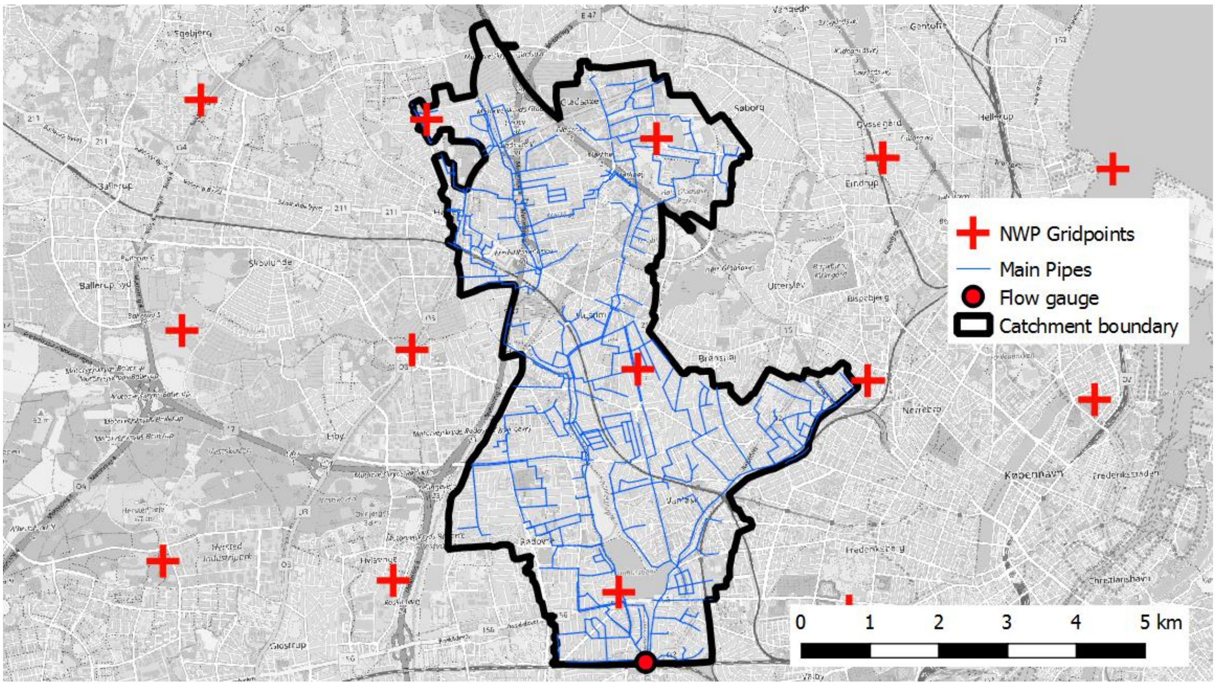

Figure 1. Overview of the Dæmningen sewer catchment including the center of the NWP grid points.

2.2 Runoff model

Stormwater flow is simulated with a conceptual model that consists of a Nash cascade with three linear reservoirs. This model contains two parameters: the effective area of the catchment and the reservoir time constant. The diurnal wastewater pattern from households and industry is simulated with a simple Fourier series as described in Equation 1:

$$\boldsymbol{WW_t = a_0 + a_1 \cos(2\pi t) + b_1 \sin(2\pi t) + a_2 \cos(4\pi t) + a_2 \sin(4\pi t)} \tag{1}$$

where a_0, a_1, a_2, b_1 and b_2 are parameters to be calibrated while t is the time of day. The parameters are calibrated on data from 2016. Validation is then done on data from 2017.

2.3 Forecast evaluation

Flow forecasts are evaluated based on their ability to predict the exceedance of a flow threshold of 4000 m^3/h. This threshold signifies the difference between high and low flow domains as initially defined by Courdent et al. (2018) for the same case study. Threshold exceedance forecasts can be evaluated with a contingency table as illustrated in Table 1. From this table, the True Positives Rate (TPR) and the Positive Predictive Value (PPV) are calculated as given by Equations 2 and 3, respectively. TPR defines how many of the observed high flow time steps that were correctly predicted, while PPV defines how many of the predicted high flow time steps that actually came true. The evaluation is based on 2165 forecasts in May-July and October-December, 2017. The observed flow exceeds the high flow threshold around six percent of the time in this period.

Table 1. A contingency table that can be used for evaluating threshold exceedance problems. Here, positive means that a given threshold is exceeded in a time step while negative means that it is not.

	Observation Positive	Observation Negative
Forecast Positive	True Positive (TP)	False Positive (FP)
Forecast Negative	False Negative (FN)	True Negative (TN)

$$TPR = \frac{TP}{TP + FN} \quad (2)$$

$$PPV = \frac{TP}{TP + FP} \quad (3)$$

3. RESULTS AND DISCUSSION

3.1 Example forecast

Figure 2 shows an example of a high flow event on June 9-10, 2017. The figure shows four consecutive forecasts. It is thus possible to see the temporal evolution of the forecasts in the time leading up to the high flow event. Of the shown forecasts, the three earliest (T-10, T-6, and T-3) over-estimate the runoff volume and predict an increase in flow before it was observed in reality. Only the forecast produced an hour before the event (T -1) manage to match the observed event, both in terms of timing and magnitude.

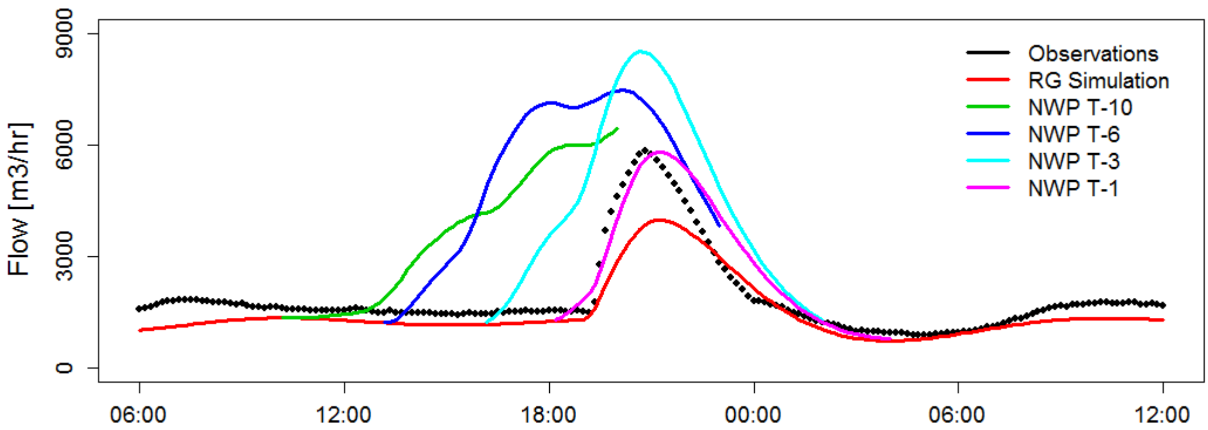

Figure 2. Example of four flow forecasts for an event on June 9-10, 2017. “T-“ refers to the time before the onset of the event in hours, while “RG simulation” is flow simulated with observed rainfall for the event.

3.2 Threshold exceedance evaluation

Figure 3 shows TPR and PPV as a function of the forecast horizon. Both measures start at the level of the simulated runoff within the first hour and then decrease as the effect of the initial conditions in the runoff model fades out. TPR starts around 0.5 for short horizons less than two hours, which means that around half of all high flow observations are correctly predicted, while it drops to around 0.2 for horizons longer than four hours. The low TPR is mainly due to many events being under-predicted (not shown here). PPV starts at almost 1.0, which means that a positive prediction is very trustworthy as almost all high flow predictions eventually come true for horizons less than 1.5 hours. This drops to around 30% for horizons beyond four hours. These results highlight the issues linked to under-prediction of runoff events, which can significantly affect the performance of NWP for operation of integrated urban drainage-wastewater systems. A possible solution could be the use of post-processing schemes as the one proposed by Courdent et al. (2018).

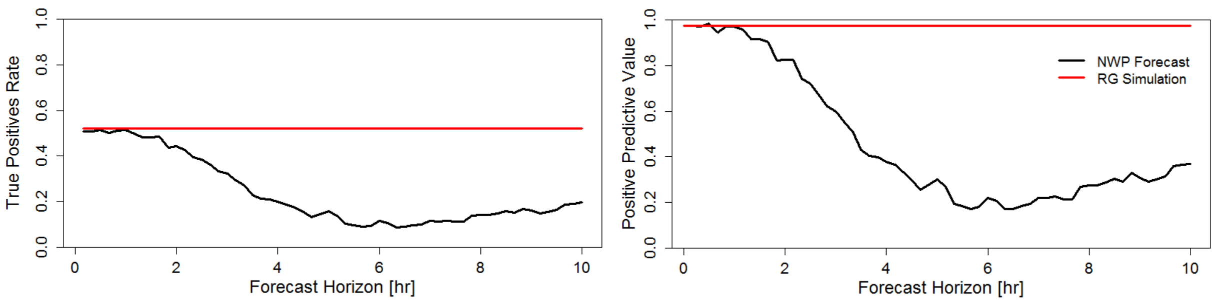

Figure 3. True positives rate (left) and positive predictive value (right) for the forecast driven by NWP and flow simulation with measured rainfall for the same period.

CONCLUSIONS

NWP models can provide realistic rainfall forecasts with longer time horizons than radar extrapolation, but suffer with regards to resolution in space and time. There is a need for more research into how NWP can be used as forcing for urban drainage models in a fruitful manner. In this contribution, we forecasted flow at the outlet of an urban drainage system with horizons up to 10 hours.

Evaluation of the ability to predict high flow events showed that the NWP-driven high flow predictions are very trustworthy on short horizons and then gradually worsen. Several events are under-predicted, which leads to only half of all high flow events being successfully forecasted on horizons less than two hours.

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